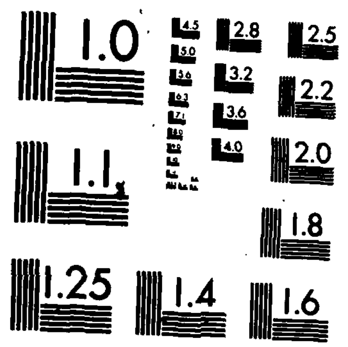
AD-A137 751   EXPERIMENTAL INVESTIGATION OF THE CHARACTERISTICS OF AN ULTRAVIOLET STORA..(U) STANFORD UNIV CALIF W W HANSEN LABS OF PHYSICS J M MADEY 31 MAR 83 AFOSR-TR-84-0094   1/1

UNCLASSIFIED   F49620-80-C-0068   F/G 20/5   NL

END
FILMED
3-84
DTIC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

AFOSR-TR- 84-0094

W. W. Hansen Laboratories of Physics
Stanford University
Stanford, California 94305

3

AD A137751

FINAL TECHNICAL REPORT

Experimental Investigation of the Characteristics of an Ultraviolet Storage Ring Laser

AF Contract: F49620-80-C-0068

1 June 1982 to 31 March 1983

Principal Investigator: John M. J. Madey

84 02 10 082

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AFOSR-TR- 84-0094	2. GOVT ACCESSION NO. AD A137 751	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) "EXPERIMENTAL INVESTIGATION OF THE CHARACTERISTICS OF AN ULTRAVIOLET STORAGE RING LASER"		5. TYPE OF REPORT & PERIOD COVERED FINAL
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) John M. J. Madey		8. CONTRACT OR GRANT NUMBER(s) F49620-80-C-0068
9. PERFORMING ORGANIZATION NAME AND ADDRESS Stanford University W.W. Hansen Lab of Physics Stanford, CA 94305-2184		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 61102F 2301/A1
11. CONTROLLING OFFICE NAME AND ADDRESS AFOSR/NP Bolling AFB, Wash DC 20332		12. REPORT DATE Mar 31, 1983
		13. NUMBER OF PAGES 14
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Making use of newly installed experimental hardware and instrumentation, we have continued our investigation of laser-induced bunch lengthening, gain, diffraction effects, and subthreshold behavior in the ACO storage ring FEL

DD FORM 1 JAN 73 1473

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

Abstract: Making use of newly installed experimental hardware and instrumentation, ~~we have~~ continued ~~our~~ investigation of laser-induced bunch lengthening, gain, diffraction effects, and subthreshold behavior in ~~the~~ ACO storage ring ~~FEL~~.

I. INTRODUCTION

The object of the research carried out under this contract is the experimental characterization of the interaction between the optical field and the circulating electrons in a storage ring FEL. Because the performance of such systems is critically dependent on the balance of radiation damping and the energy spread induced by the FEL interaction, it is evidently desirable to experimentally verify the basic theory which has been developed to describe these systems, and to secure as much data as possible on those collective, time dependent and diffractive effects which can modify their behavior.

In addition, the ACO experiment is the shortest wavelength FEL to be brought into operation to present date. The technical problems we have encountered during the experiment - particularly the UV optical damage problem - are a valuable indication of the general issues to be resolved in the development of short wavelength FEL's.

Major progress has been made in the characterization of the ACO FEL during the period of this contract in each of the areas of interest, as summarized in the succeeding sections of this report and the appended publications. We note that although only sub-threshold data was secured during this contract, laser oscillation was achieved in June, 1983. Additional data on the oscil-

lator will be secured with support of the successor contract to F49620-80C-0068.

II. IMPROVEMENTS TO EQUIPMENT AND INSTRUMENTATION

Much of the progress achieved during this contract was made possible by improvements to the experimental apparatus and instrumentation. By the terms of our collaboration with the LURE laboratory and Orsay, LURE assumed responsibility for the construction and operation of the storage ring, undulator, and laser optics while Stanford assumed responsibility for the optical and electron beam diagnostics. A new vacuum system and permanent magnet undulator, NOEL, was installed on the ACO storage ring just prior to the start of this contract, and was further modified during the contract for operation as an optical klystron. The effective and reliable operation of the NOEL undulator and klystron played a key role in the success of our experiments.

Important additional modifications were also carried out by LURE during this contract, in particular, the installation of the optical cavity for the oscillator experiments. LURE also carried out a more-or-less continuing effort to improve storage ring performance by optimization of the operating parameters for ACO, and by preparing for positron injection to eliminate the

ion effects which act to reduce the charge density of stored electron beams.

With respect to instrumentation, the Stanford group completed its implementation of a digital data acquisition and averaging system for use in the gain, bunch lengthening, and spontaneous radiation experiments. Software was also written to permit rapid computation of the absolute bunch length from the raw spectral data, including corrections for the detector, cable, and amplifier response. Finally, a broad band capacitive pickoff and envelope detector were added to ACO to permit characterization of the multipole number and strength of the coherent electron beam instabilities observed at high current.

As joint efforts of the Stanford and LURE groups, an optical system was developed to measure the magnitude and spatial distribution of ultraviolet-induced absorption in the mirrors in the oscillator experiment, and a Reticon photodiode array was incorporated in a system to monitor the radial distribution of the stored electrons in ACO, and of optical power in the argon-ion laser beam used in the gain and bunch lengthening experiments.

III. NEW EXPERIMENTAL RESULTS

The experimental results obtained with this new equipment are summarized below. A more complete description of these

results can be found in the referenced publications and pre-prints.

Electron Bunch Heating (low current): Using the NOEL undulator and an external argon-ion laser to drive the interaction, we have secured comprehensive data on the laser-induced electron energy spread as functions of laser power, wiggler magnetic field, storage ring RF voltage, optical mode overlap, and detection frequency. In the limit of low electron currents, the data appears to be in reasonably good agreement with the behavior computed assuming non-interacting electrons and stochastic optical phase.[1,2]

Electron Beam Heating (high current): Extension of the bunch lengthening measurements to the high current regime have disclosed a range of anomalous phenomena very different from the behavior observed in the low current regime, including laser-induced electron cooling, and complex time-dependent oscillations in bunch length and energy spread. Though no theory is presently available to explain these phenomena, observations indicate that this anomalous behavior is associated with the fractionation of the electron distribution into charge multipoles, the instability responsible for the general increase in energy spread and bunch length in ACO at high current (see also "Coherent Mode Thresholds," below).[3]

Subthreshold Behavior: Using the undulator, measurements were made of the laser gain in the amplifier configuration, and sub-

threshold behavior in the oscillator configuration, using the new optical cavity. Though the gain achieved in the oscillator experiments were less than the cavity losses, clear evidence of regnerative amplification was seen in the dependence of power output on cavity length and the change in shape of the optical emission spectrum.[1,5]

<u>Optical Klystron Measurements</u>: The bunch lengthening, amplification and sub-threshold experiments were each repeated using the optical klystron following its installation. The increase in gain obtained using the klystron led to significantly increased power output and line-narrowing in the sub-threshold experiments, though UV radiation damage to the mirrors remained high enough to keep the system below threshold (see also "Mirror Damage," below).[1,5,7,10]

In addition to providing higher gain, it was found during these experiments that the klystron also provided diagnostic information not readily available using the undulator. As demonstrated in these experiments, the amplitude of the fringes in the klystron's spontaneous radiation spectrum are a sensitive function of the electron energy spread and emittance. The information on energy spread and emittance obtained from analysis of the fringe pattern provides an important compliment to the

measurments of bunch length and radial dimensions obtained through our optical observations of the bunch.

Mirror Damage: With both the undulator and the klystron, significantly increased mirror losses were observed following installation of the mirrors and operation of the experiment. Observations indicate that the increased absorption includes two components: one associated with the initial installation of the mirrors in the vacuum and a second component proportional to the operating time of the experiment. The first component is believed due at least in part to contamination of the mirrors during pump out and to desorption of oxygen and water vapor from the mirror surfaces. The second, and more troublesome is due to ultraviolet radiation damage.

In a series of experiments, it was shown that the UV damage is due to the radiation emitted by the electrons in the undulator magnets, as opposed to the synchrotron radiation emitted in the bend magnets of the ring. It was also shown that both cavity mirrors were damaged, indicating that the damaging radiation was within one of the reflection bands of the mirrors, and that mirror reflectivity could be at least partially restored by air bakeout. The damage mechanism is believed to be of color center formation or oxygen desorption from the first layer of the dielectric stack.[1,4,5,6]

While these mirror damage mechanisms have proven especially troubling for the ACO experiment due to its small gain, UV damage

may continue to prove troublesome even for high gain experiments by increasing the thermal power loading. Mirrors intended for FEL high power applications in the visible will need to have reflectivities comparable to the initial reflectivity of the mirrors in the ACO experiment. An increase in absorption by a factor of 10 during operation would raise serious questions concerning mirror survival.

Coherent Mode Thresholds: By observing the frequency spectrum of the envelope of the signal induced by the electron beam in ACO on a capacitive pickoff electrode, it is possible to identify the thresholds in current and RF voltage at which the electron bunch fractionates into charge multipoles in the anomalous lengthening regime. Simultaneous measurements of the laser-induced bunch-lengthening effects indicates that the transition from the low-current bunch-lengthening regime to the anomalous high current regime coincides with the onset fractionation. The observation suggests that the reduction in bunch length caused by the laser interaction in the high current regime occurs as a consquence of the disruption of the dipole and higher order multipoles by the laser, and the consequent reduction of the RMS energy spread and length of the fractionated bunch.[3]

Diffraction Effects: Careful observation of the radial distribution of the optical radiation emitted by the electron beam as a consequence of the laser interaction in the amplifier experiments indicates a characteristic admixture of higher order radial modes.

The observed distribution of power is a good match to the coupling expected due to the finite filling factor in the experiment. The effect provides a useful example of radial mode evolution in the FEL and could conceivably be exploited to improve the gain of FEL oscillator by shaping the mirrors to reflect the radiation emitted in the higher order modes through the interaction region.[9]

Careful observation of the far field spontaneous emission spectrum and gain of the optical klystron also indicate a small but finite shift of the fringe structure in the gain measurements. The effect is in apparent agreement with the shift expected due to the characteristic π phase shift in the interaction region of the incident gaussian laser beam used in the amplifier experiments as compared to the plane wave excited by the electrons in the far-field spontaneous spectral measurements.

IV. OTHER ACCOMPLISHMENTS

Conferences: The Orsay experiment has been highlighted at a number of international conferences. Invited papers reviewing the status of the experiments have been presented at CLEO,[5] Lasers '82,[7] the Hamburg Synchrotron Radiation Conference,[6] and the Bendor FEL Conference.[1]

Graduate Student Dissertations: The bunch-lengthening data taken during the experiment is the subject of a Ph.D. dissertation by Kem Robinson.

V. FUTURE PLANS

Although the data taken during this contract year largely satisfies the basic objectives of the research program at Orsay, the operation of the oscillator experiment in June, 1983, has created an opportunity to secure substantial additional data on the ACO system. Present research funds provide for a limited continuing technical liaison effort at Orsay, and we will use these funds to secure as much data as possible on the oscillator.

REFERENCES

1. M. Billardon, D. A. G. Deacon, P. Elleaume, J. M. Ortega, K. E. Robinson, C. Bazin, M. Bergher, J. M. J. Madey, Y. Petroff, M. Velghe, "Recent Results of the ACO Storage Ring FEL Experiment," Proceedings of the Bendor Free Electron Laser Conference, Journal de Physique Colloque,Cl, 44, Supplement to No. 2, February 1983), p. Cl-29.
2. K. E. Robinson, D. A. G. Deacon, M. F. Velghe, J. M. J. Madey, "Laser Induced Bunch Lengthening on the ACO Storage Ring FEL," IEEE J. of Quant. Elect., QE-19, 3 (March, 1983) pp. 365-368.
3. K. E. Robinson, J. M. J. Madey, M. F. Velghe and D. A. G. Deacon, "Anomalous Laser Induced Bunch Lengthening on the ACO Storage Ring Free Electron Laser," IEEE Trans. Nucl. Sci., NS-30, No. 4, August 1983, pp. 3088-3090.
4. P. Elleaume, D. A. G. Deacon, M. Billardon, and J. M. Ortega, "UV and VUV Degradation of very High Reflectivity Mirrors for Use in a Storage Ring Free Electron Laser," Conference on Lasers and Electro-Optics (CLEO'83) OSA/IEEE Digest of Technical Papers, 17-20 May, 1983, Baltimore, Maryland, paper THJ3, p. 182.

5. C. Bazin, M. Bergher, M. Billardon, D. A. G. Deacon, P. Ellaume, J. M. J. Madey, J. M. Ortga, Y. Petroff, K. E. Robinson, M. F. Velghe, "Progress and Problems in Storage Ring Free Electron Lasers," Conference on Lasers and Electro-Optics (CLEO '83) OSA/IEEE Digest of Technical Papers, 17-20 May 1983, Baltimore, Maryland, paper THJ2, p. 182.

6. D. A. G. Deacon, "Storage Ring Free Electron Lasers: Experimetnal Progress and Future Applications," Nucl. Inst. and Meth. 208 (1983) 171.

7. M. Velghe, M. Bergher, C. Bazin, M. Billardon, D. A. G. Deacon, P. Elleaume, J. M. J. Madey, J. M. Ortega, K. E. Robinson, "New Results of the ACO Storage Ring Free Electron Laser," Proceedings of the International Conference on Lasers '82, December 13017, 1982, New Orleans, LA.

8. P. Elleaume and D. A. G. Deacon, "Transverse Mode Dynamics in a Free Electron Laser," Submitted to Applied Physics B, August, 1983.

9. P. Elleaume and D. A. G. Deacon, "Evolution of the Transverse Modes in an FEL and Applications to the Orsay Experiment," to be published in the Proceedings of the Orcas Island FEL Conference.

10. K. E. Robinson, D. A. G. Deacon, M. F. Velghe and J. M. J. Madey, "Additional Bunch Lengthening Results on the ACO SRFEL," Proceedings of the Bendor Free Electron Laser Conference, Journal de Physique Colloque C1, 44, Supplement to No. 2 (February 1983), pp. C1-379-382.

11. M. Velghe, "Design and Operating Experience on Laser Cavity in a Vacuum of 10^{-10}torr," Proceedings of the Bendor Free Electron Laser Conference, Journal de Physique Colloque C1, 44, Supplement to No. 2, (February 1983), p. C1-387.

END

FILMED

3-84

DTIC